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Sea floor expression of sediment extrusion and intrusion at the El Arraiche mud volcano field, Gulf of Cadiz.

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The El Arraiche mud volcano field was discovered in May 2002 in the Moroccan Atlantic margin in the Gulf of Cadiz. It consists of 8 mud volcanoes of varying size and shape just below the shelf edge (figure 2). The largest mud volcano in the field (Al Idrissi mud volcano) is 255 m high and 5.4 km wide, the smallest we observed is only 500 m wide and 25 m high. The morphology of the mud volcanoes consist of, from base to top: a moat around part of the base of the mud volcano cone, an irregular slope characterized by radial outward sediment flows, terraces and/or depositional sediment flow escarpments (lobe fronts), a crater depression or a flat top, and a central dome.

The 2002 surveys by the RV Belgica and the RV Logachev yielded detailed swath bathymetry over the entire area, dense grids of high-resolution seismic data, very high-resolution deep-tow sub bottom profiles, side scan sonar mosaics over the major structures, selected video lines, TV-grabs, dredge samples and gravity cores.

The large amount of sea floor data and the clear shape of the larger mud volcanoes prompted us to focus on the morphology of the mud volcano cones. Although mud volcanoes are prominent features in the submarine sea-scape little attention has yet been given to their small-scale morphology. Mud volcanoes in their broadest sense refer to any extrusion of mobilized sediment. Mud volcanoes sensu strictu are cone-shaped with central vents. They are often considered as a sedimentary analog of stratovolcanoes, built by stacked sediment flows issued from a central crater or subsidiary vents at the flanks. The morphology of mud volcanoes sensu stricto is thus largely attributed to extrusion processes whereas the effect of intrusive processes remains unclear. High-resolution seismic profiles provide little information about the internal structure of a large mud cone, due to acoustic blanking. We can in this case only deduce formation processes from the information available at the surface.

On basis of the observations we conclude that these large cone-shaped mud volcanoes result from a combination of intrusive and extrusive processes. Sediment flow deposits on the slopes range between two end-members. Flows with low yield strength (type I) extend to the base of the slope and create a steepening convex slope profile with a low overall slope angle (5° - 6°). Flows with a high yield strength (type II) freeze on the steep slope and create an irregular slope profile with almost constant slope angle (8° - 10°). Within the crater, several vents issue fluidised sand and small debris flows that consist of mud breccia with cm to m-sized clasts in a mud matrix. The extrusive sediment flows shape the surface of the mud volcano but in this study we also observe morphological elements that do not appear to correspond solely to extruded sediment deposits and may be partly result from sediment intrusion processes. The central dome and the concentric pattern of continuous terraces and steps on the slope are interpreted to result from different phases of uplift by sediment intrusion, each possibly followed by collapse due to degassing or dewatering. Intrusive processes may involve shallow-seated diapirism caused by density re-equilibration within the thick pile of remoulded mud volcano sediments or uplift and volumetric expansion by injection of sedimentary dykes.